33 The Changing Science and Technology Environment

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This chapter focuses on three areas. The first area is innovation as a context for research, focusing on the balance between technologies between the east and west coasts as producers of innovation. The second area is the research enterprise itself, both at the national and international levels. The third area is the connection between innovation and research, focusing on university patenting and patent-to-paper citations (that is, the local connection). A recently published paper discusses this in more depth.*

Behind this analysis is a framework related to recent European theoretical perspectives in which research is placed in the context of national science and technology systems, and interest focuses on interactions within the system, and how these might be changing. My field is bibliometrics, so I use patents in the patent and paper databases, within which I believe that there are some profoundly interesting patterns emerging.

Innovation

Figure 1 shows the growth in patenting in three broad technology areas: information technology, health technology, and other. Compared with other technologies, the increase in patents in the information and health technologies is striking. It would be hard to overestimate the dynamism of patenting growth in information technologies (computers, telecommunications, and semiconductors) and health technologies (pharmaceuticals, biotechnology, and medical electronics and medical equipment).

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Figure 1
Growth in Patenting

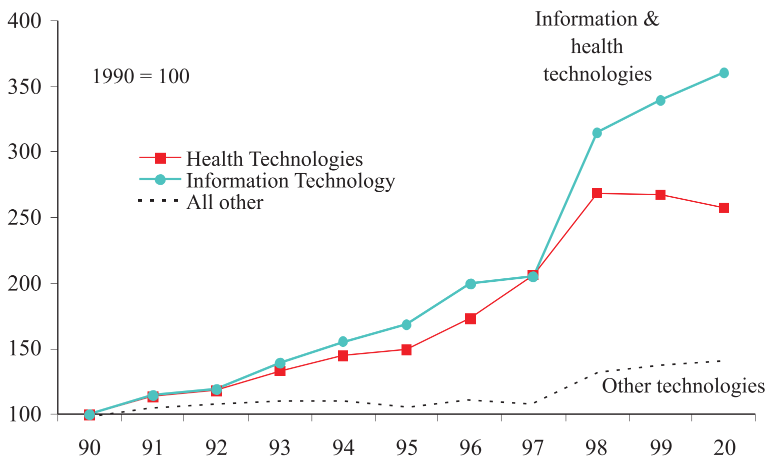
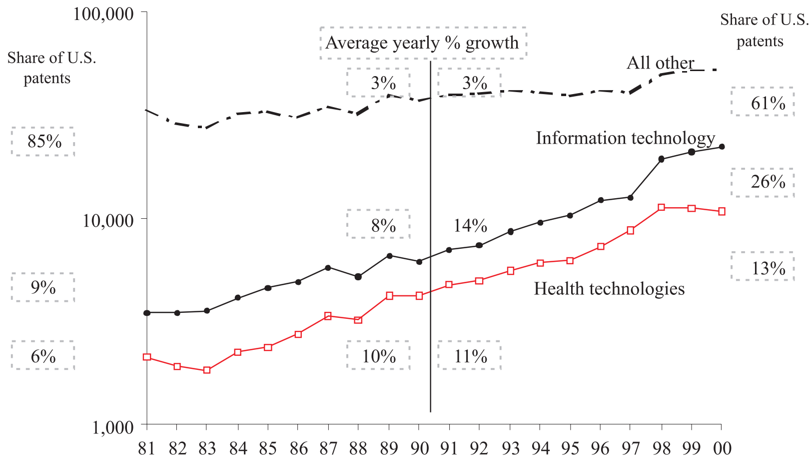


Figure 2 gives the average yearly percentage growth of U.S. patents by area. In recent years, we have seen growth of 14 percent per year in the number of patents produced by American inventors in information technology and 11 percent growth in the number of patents in health technologies, compared with three percent growth in the more traditional areas.

The number of patents in information and health technologies is increasing almost exponentially in this country. This reflects a genuine change in the way things are done in our innovation system. It has consequences for science, of course, both because of the fast growth and the absolute size of these technologies. The more traditional technologies used to account for 85 percent of U.S. patents, and now they account for about 60 percent. Since the government supports science, motivated in large part to support innovation, we would expect to see a shift in government science-funding priorities because of the shifts in the balance of technologies that are out there and where the innovation is coming from.

The next shift in balance is a shift between the east and west coasts, here examined using U.S. Census divisions. The Pacific division includes California, Nevada, Oregon, Washington, Hawaii, and Alaska, and is a player in both science and technology. The East North Central divi-

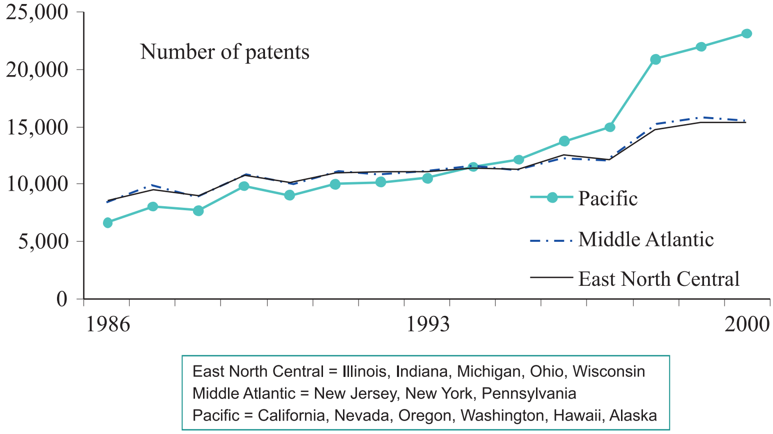
Figure 2
Patenting in Health and Information Technology Grows Rapidly



sion (the "industrial heartland") includes Illinois, Indiana, Michigan, Ohio, and Wisconsin, and is also a large patenter. The Middle Atlantic region (New Jersey, New York, and Pennsylvania) is a big player in both patenting and papers. The South Atlantic (Delaware, Maryland, District of Columbia, Virginia, West Virginia, North Carolina, South Carolina, Georgia, and Florida) is a big player in publishing. These four regions are the largest patenting and publishing regions. Figure 3 shows the number of patents coming out of the three largest patenting regions—Pacific, Middle Atlantic, and East North Central.

In the 1980s, the Middle Atlantic and East North Central regions were essentially tied as the largest patenters. In the mid-1990s, patenting in the Pacific region started increasing and the Pacific region now produces many more patents than the other two regions. The West has now pulled ahead and opened up a gap with the East Coast. The growth in the West has policy consequences on the local level. For example, New Jersey and Pennsylvania are now having more difficulty attracting top young technical people who often prefer California.

Figure 3
Patenting from the Pacific Region Overtakes the Largest East Coast Regions



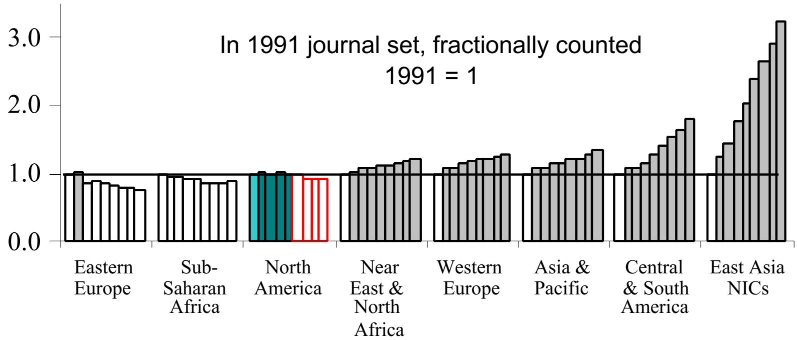
The Research Enterprise

Is the same thing happening with papers? The story here is slightly different. In the late 1980s, the South Atlantic region and the Middle Atlantic region were the two largest publishing divisions in the country, and Pacific was number three. Now things have changed, and the Middle Atlantic is falling off and losing its preeminence, dropping to number three. South Atlantic is number one and Pacific is number two. We see a real shift toward the South and West in where the action is in science.

We are going to see a shift as well at the international level. Figure 4 divides the world into regions shows the growth index of the number of papers published as measured in the Institute for Scientific Information's (ISI) *Science Citation Index*. I took the number of papers published in 1991 and subsequent years, and divided the number of papers in each year by the number in 1991. This enables us to compare the growth rates irrespective of publishing sizes.

We see the dynamism of the Asian and Latin American science systems. A lot of countries have focused on building their science enterprises and their infrastructures in recent years. The Organization for Economic Cooperation and Development and the National Science Board's *Science and Engineering Indicators* give a sense of what this

Figure 4
Growth in Number of Papers 1991–1999



Number of papers in 1999:

31,800	3,900	197,400	9,700	202,500	91,900	12,800	16,900

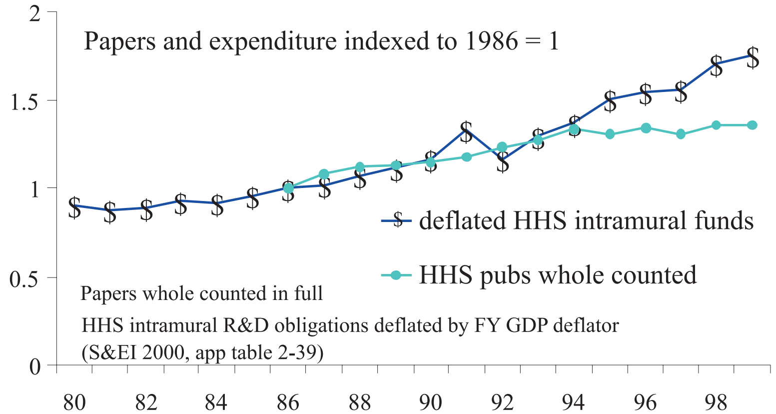
involves. Often countries have increased money for grants and infrastructure and for Centers of Excellence. We also see new mechanisms to allocate money based on performance and hence on evaluations. In other countries, when governments initiate national programs of evaluation, this does tend to encourage publishing in journals included in the *Science Citation Index*, which because they are internationally peer reviewed offer governments of smaller countries objective validation of the quality of their scientists using international standards.

In three regions, publishing is declining in absolute terms—Eastern Europe, Sub-Saharan Africa, and North America. The domestic policies behind that are unclear to me at the moment.

Figure 5 measures intramural research expenditure by the U.S. Department of Health and Human Services in constant dollars against the growth in publication output. You can see a parting of the ways in about 1995 and continuing. It is unclear why this is happening, and more investigation is needed. Something might be going on there, and it might be very serious.

The next shifting balance in the research system is the balance in collaborative work. The single-investigator research project is basically extinct. The person who founded the bibliometric area and first started looking into this, Derek Priscilla-Price, discovered that pretty early.

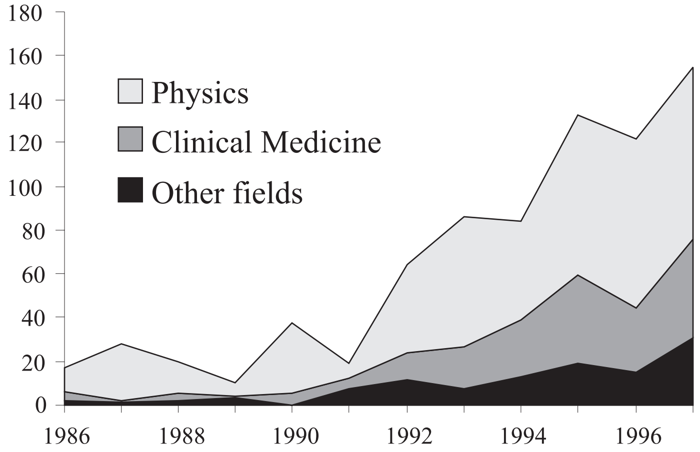
Figure 5
Comparison of Growth in HHS Intramural Expenditure Outpaces Growth in Publications



The same now may be happening to single-institution research. Research where people collaborate across institutional boundaries is now the rule and not the exception in the American system. That happened in May 1990 (if you do a little interpolation). Distributed science is now the norm, not the exception.

A former graduate student of mine, Tiago Santes Perrera, is looking in detail at collaboration. He found that the concept of the well-funded laboratory used to dominate, especially in British science policy. In this system, the government traditionally had a responsibility to fund scientists. The scientists received twelve-month salaries, and they got money for equipment and instrumentation so they could conduct research at the international frontiers. In the American context, this would be the goal of American scientists and their universities. But Perrera thinks this has changed. The goal now is the well-distributed laboratory. This is a laboratory with enough resources that it can contribute to collaborative efforts. It also has the contacts, in collaboration with other people, to pull something together to address increasingly complex problems, irrespective of the institutional boundaries that may separate them and their equipment. There are profound policy consequences here, particularly, for example, in the evaluations area. For example, how much

Figure 6
Number of Papers Listing Addresses from Ten or More Countries



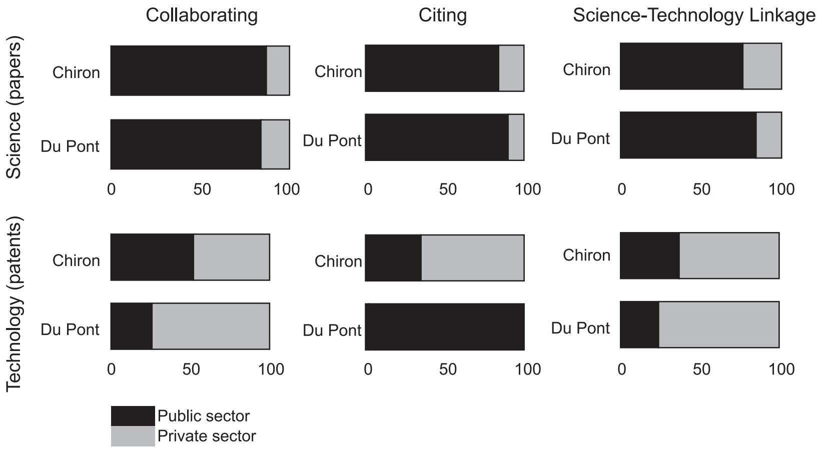
research belongs to each party? We have to start taking seriously the fact that collaboration is now the rule, not the exception.

The next issue is a very small phenomenon. Figure 6 shows the number of papers that list addresses from ten or more countries, which is a very, very distributed research project. The growth starting around 1991, particularly in physics, is interesting. This may be an example of how information technology, e-mail, and other technologies have facilitated distributed research.

Public-Private Connections

University patenting is rising. It is becoming particularly significant, amounting to about 15 percent of assigned patents (that is, excluding individual-inventor patents) in this country. Some of the tensions this is causing are increasingly discussed. I will focus on the consequences of this from a corporate perspective, looking at what I call the public-private shifts that are shaping the corporate environment. We can see these shifts by looking at who is collaborating, who is citing, and who is cited by company.

Figure 7
Public-Private Composition of Chiron and DuPont's Collaboration and Citation Networks



Each bar displays the number of public and private sector institutions among the 100 most citing/cited/collaborating institutions in each dimension.

Figure 7 shows two companies—Chiron, a newcomer, and DuPont, a more traditional company that has been around for a long time. The upper section shows science and what is happening in publishing. The lower section shows technology and what is happening in patenting. The top left bar shows Chiron and its collaborations in publishing papers. I took all the institutions that collaborated with Chiron on their papers and ranked them according to frequency of collaboration. Then I looked at just the top 100 and asked how many of these top 100 institutions are public and how many are private. The plot of that is the top bar. The other bars were derived in the same way from analysis of paper and patent citation and collaboration patterns.

Chiron's world is a little bit more balanced, a little bit more complex. DuPont's world is more traditional. In technology, you would expect the private sector to patent. So, in the patenting collaborations and citation relationships, you would expect to see private companies, and for DuPont, that is pretty much true. For Chiron, though, it is a little messier. They have more balance and more participation by the public sector. For them, technology comes from both the private and the public sectors.

In science (not so much in Column x, but in Columns y and z), Chiron is moving more in that direction. In other words, they have a little more participation by the private sector in their science citing and science-technology relationships.

We see in these bar displays that the world is getting more complex. The roles are more blurred, the boundaries are fuzzier. We see this in the policy mechanisms that are striving to support collaborations between the public sector and private sector. We also see it in the different and more complex funding mechanisms that we now have that we did not have 10 or 20 years ago.

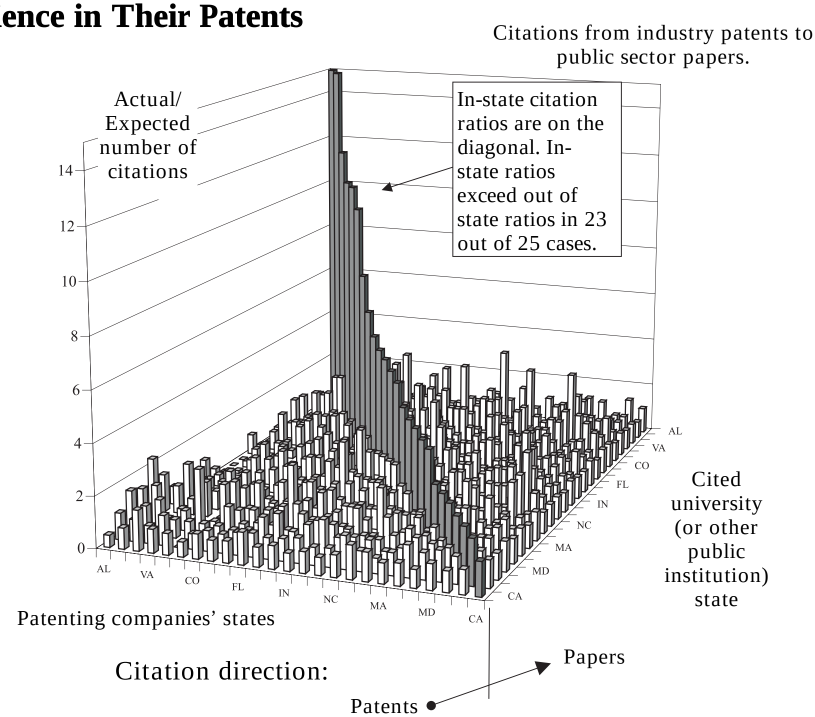
Local Importance of Public Sector Research

In some cities, the contribution of the public sector in innovating and producing technology as evidenced through patenting is substantially more important than the contribution of the private sector. In Boston, the Massachusetts Institute of Technology is now the largest patenter, and Harvard University is number five. In Washington, D.C., the National Institutes of Health is the largest patenter. In San Diego, the top ten patenting organizations include the Scripps Clinic Research Foundation, the University of California, the Salk Institute for Biological Studies, and the La Jolla Research Foundation. From the local perspective, things can change dramatically with this situation.

CHI Research, Inc. has repeatedly pointed to this growth in referencing from patents to papers in scientific journals, arguing that these references make visible the connection between research and innovation. If you look at the references from patents to papers, you see papers coming out of the public sector. It is a very direct way of looking at the connection between science and technology.

This referencing can also make visible a phenomenon where we find that patents that are assigned to companies reference in-state papers produced by public sector institutions more often than we might expect. To see this, I built a database of patent to paper citations. On one side, I had all patents granted in the years 1993–1997 that listed a U.S. address and were assigned to companies. On the paper side, I had all the papers they referenced that were indexed in the *Science Citation Index*, published not more than ten years prior to the referencing patent, listed a U.S. address and, most importantly, came out of the public sector (i.e., did not list a company name). In other words, the database contained patents from companies and papers from the public sector. Figure 8 shows the result.

Figure 8
U.S. Companies Preferentially Cite In-state Public Sector Science in Their Patents



Expected # of citations = "patent state's" # of citations to all states multiplied by "paper state's" share of cites received from all states.

The first thing you see is that most states' patents reference California more than any other state, because California is so big and produces so much of our nation's science. However, if you look at the ratios of actual to expected patent to paper citations, you find that for most states, the patents from a state favor to some degree the papers from that state. This is what is on the graph, because the graph shows actual expected citation ratios from the patenting states to the paper states. The diagonal is the in-state line. In 23 out of 25 cases, the in-state actual expected ratio exceeds the highest out-state ratio.

This is really interesting from a policy perspective, because it is often difficult at the local level to explain why we should fund science, because people argue that they can get science from anywhere. And local science is important for local technology. Indeed, scientific results are comparatively easy to access (in conferences, literature, the Internet, and so on) and the distance between the users and the scientist's laboratory does seem to be irrelevant. You would think that a company that is advancing leading-edge technology and building on recent research should be able to get its science from anywhere in the world, and they do. But these results show that local science is important for local technology. And this type of data offers pretty inhospitable circumstances if you want to find any traces of personal relationships needed to exchange complex, tacit knowledge. It is the necessity of face to face interaction in technology transfer that accounts for this result. The upshot is that you can read the literature and find it at a distance, but by that time, so can everyone else. The competitive edge comes in those early days when you still need the personal relationships, and when things are very complex. This is why you see clusters in innovation.

Conclusion

The world is getting more complex, and the traditional roles are mixed up. Information and health technologies have become much more prominent in the technological landscape. Innovation and research output on the West Coast has overtaken traditionally stronger areas on the East Coast. Europe has overtaken the United States in publication output, and many countries are more dynamic than the United States. People collaborate, as most science is produced in networks of researchers collaborating across institutional boundaries. University patenting has risen enough to be significant in the health technologies. Public sector/private sector roles in research and innovation are getting more complex and less differentiated. From the local perspective, the public sector can be the leading source of patented technology. And research does have an enhanced impact on in-state technology. These are substantial long-term trends.

Endnote

* Hicks, D., Breitzman, T., Olivastro, D., Hamilton, K. “The Changing Composition of Innovative Activity in the U.S.—A Portrait Based on Patent Analysis.” *Research Policy,* 30 (2001): 681-703.